(54) Title: SUBSTANCE DETECTION DEVICE USING MONOENERGETIC NEUTRONS
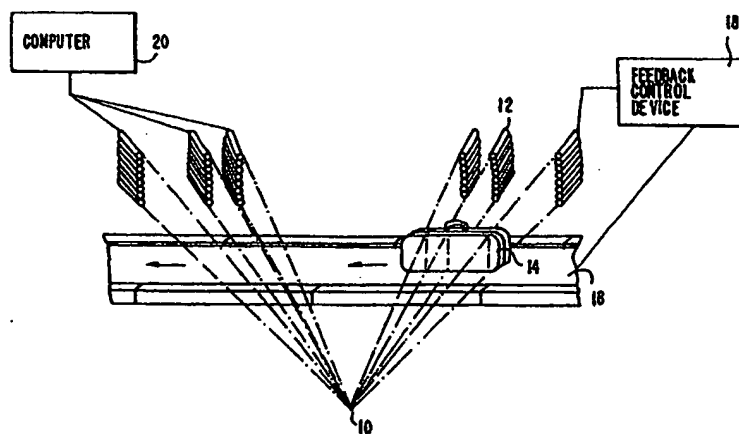
(57) Abstract

A method and apparatus for non-invasively determining the internal composition of objects are disclosed. The object of interest (14) is probed with low energy, monoenergetic narrow beams of fast neutrons. The object (14) is generally placed on a conveyor belt (16) which is positioned between the accelerator (10) and the detectors (12). Detectors (12), positioned at radial angles corresponding to the resonance energy levels of certain preselected elements, measure the neutrons that are not absorbed or scattered by the elements in the object (14) and thus pass straight through the object (14). The information obtained from the detectors (12) can then be used for subsequent tomographic reconstruction.

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TITLE OF THE INVENTION

Substance Detection Device
Using Monoenergetic Neutrons

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S.
Provisional Application Serial No. 60/016,578, filed
April 30, 1996.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates generally to methods and
apparatus for non-invasively determining the composition
of objects, particularly closed containers or otherwise
inaccessible objects. More particularly, the present
invention relates to a method and apparatus that uses
neutron scattering to identify the existence of
particular elements that are abundant in explosives.

Description of the Invention

The need exists for a rapid, safe, accurate and
non-intrusive inspection system for determining the
presence of certain elements in objects such as suitcases
and luggage. This need is especially great for
identifying the presence of explosives or explosive
devices in suitcases or any other parcel to be brought
upon an airplane.

It is well known that essentially all
explosives are both oxygen and nitrogen rich. One way to
detect concealed explosives is to use penetrating
radiation, such as neutrons, and to detect the
interaction of the neutrons with oxygen and nitrogen
atoms.

Uncharged particles, such as neutrons and
photons (gamma rays) have the potential to penetrate
relatively large dense objects and to identify particular
elements of interest. Several detection devices have

utilized the absorption and/or scattering patterns of the
neutrons or photons as they interact with certain
elements present in the object being inspected.

A number of the processes used to detect

5   concealed explosives have irradiated suspicious
containers with thermal neutrons or, alternatively, with
pulsed fast neutrons. Both systems measure the emitted
gamma rays produced by the absorption of a neutron by the
element of interest. The techniques have involved

10 thermal neutron analysis (TNA) described by R.R. Smith in
Substance Detection Systems, Proc. SPIE 2092, pp. 301-306
(1994) and pulsed fast neutron analysis (PFNA) described
in *Nucl. Inst. and Meth.* B 79: 593-596 (1993) by Z.P.
Sawa.

15   In thermal neutron analysis systems ("TNAS"),
very low energy neutrons (at or about .025 eV) are
employed to bombard a sample under investigation. The
nuclei of component atoms capture these neutrons and emit
photons which are then detected. A significant problem

20 with this method is that the radioactivity may persist
for a period of time presenting a potential health
hazard. In addition, TNAS exhibit both poor spatial
resolution and poor sensitivity and are generally only
potentially practical for detecting relevant quantities

25 of explosives when used in combination with x-ray
machines.

Pulsed fast neutron analysis is limited in
resolution and detection time due to neutron attenuation
and scattering, detector response time, and time

30 correlated effects such as gamma ray scattering. In
addition, a complex high-energy pulsed accelerator is
needed, in conjunction with time-of-flight systems.

Gamma ray nuclear resonance absorption (GNRA)
described in *Substance Detection Systems*, Proc. SPIE

35 2092, pp. 307-316 (1994), is a method which probes a
single element (typically nitrogen) with gamma rays of a
particular energy. The gamma rays excite the nitrogen

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nucleus which promptly returns to its lowest energy
state, emitting a cascade of gamma rays in the process.
Detecting the cascade signals the presence of nitrogen.
This technique can only practically detect a single
5　element, generally nitrogen.　Thus, it is far more prone
to false alarms than a multi-element detection system
which includes, at a minimum, nitrogen and oxygen.

Fast neutron transmission spectroscopy (FNTS)
is another nuclear detection method used to identify
10　particular elements of interest.　FNTS, as described in
Overley J.C. et al., *Nucl. Instr. and Meth.* B99:728-732
(1995) and Sale, K.E., *Substance Detection Systems*, Proc.
SPIE 2092, pp. 263-270 (1994), uses a high intensity
pulsed polyenergetic neutron beam.　An attenuated neutron
15　energy spectrum is assessed by time of flight.　There are
a number of significant drawbacks to using this
inspection system due to the fairly complex high energy
pulsed accelerator that is needed in conjunction with a
time of flight system.　In addition, sensitivity is quite
20　limited because a fairly small decrease in the overall
unattenuated signal is sought in a field in which there
are significant background signals from neutron
scattering.　United States Patent No. 5,142,153 to
Gomberg, discloses a method and apparatus for detecting
25　the presence of a preselected element in an object such
as a suitcase.　In this particular system, a neutron beam
is directed into the object and the neutrons that are
resonantly scattered by the preselected element are
measured.　Since it is the scattered neutrons that are
30　being measured, banks of detectors are needed at a
variety of locations depending on the direction of the
scattering.　The detectors used are standard neutron
detectors containing a neutron responsive material as
well as a sensitive material having a resonance at a
35　preselected energy.

United States Patent No. 5,278,418 to
Broadhurst describes a method for detecting the presence

of oxygen and nitrogen in a container. High energy
neutrons are passed through a suitcase. The neutrons
that penetrate the object of interest and pass through to
the other side are detected. The detectors used are
5   standard neutron detectors. The accelerator focuses a
proton beam upon a boron target in order to create the
neutron beam. The proton beam is periodically subjected
to an energy degrading medium upstream of the neutron
generating target in order to modify the energy of the
10   protons and thus to change the energy of the neutrons so
that different elements can be detected. A major
disadvantage of this approach to changing the energy of
the neutron beam is that proton multiple scattering
inside the degrading medium produces a non-monoenergetic
15   proton beam and thus a non-monoenergetic neutron beam.
        Each of the explosive detector systems
described has significant drawbacks or disadvantages. In
particular, these devices generally utilize accelerators
that produce high energy neutrons with a broad spectrum
20   of energies. The absorption/scattering of neutrons
traveling at specific energies are difficult to detect
given the large number of neutrons that pass through the
object without interaction. Thus, the "fingerprint"
generated from the device is extremely small, difficult
25   to analyze, and often leads to significant numbers of
false positive or false negative test results. In
addition, the accelerator needed to produce the high
energy neutron spectrum is large, expensive, and requires
extensive protective shielding. Moreover, at these high
30   energies, the neutrons can induce nuclear reactions in
the element being scanned and convert the elements of the
object into a radioactive form (neutron activation).
        "Time-of-flight" detection techniques are
frequently employed in PFNA and FNTS to provide energy
35   discrimination to high energy neutron detectors. In
time-of-flight detection, pulses of neutrons are
directed onto an object. A detector is activated in

synchrony with each pulse so as to sample (measure) the
scattered or transmitted neutrons on a temporal and hence
energetic basis. Due to their complexity, time-of-flight
techniques are problematic for large-scale explosive
5   detectors and require a pulsed neutron source, fairly
large source/detector geometries (i.e., a long flight
path) and sophisticated timing circuitry. The long-term
reliability of such systems is particularly uncertain.
        The apparatus of the instant invention
10   addresses the problems inherent in other devices and
provides a detector system which uses low energy
monoenergetic fast neutrons to identify the number and
spatial distribution of specific elements in the object
being examined. The use of monoenergetic neutrons
15   results in a number of significant advantages over these
other methods of explosive detection. The use of low
fast-neutron energies requires a comparatively low energy
proton beam for the neutron generating reactions. This
allows for a small, simple, economical and reliable
20   accelerator system. The generation of low energy fast-
neutrons also can allow a correlation between the angle
of the neutron beam and the outgoing neutron energy, so
that monoenergetic neutron beams can be utilized. Such
exact angle/energy correlations disappear at higher
25   energies.
        Further, because low-energy fast neutrons are
used and time-of-flight analysis is not required, and
because the apparatus does not require extensive
protective shielding, the physical "footprint" of the
30   equipment is small. Furthermore, because only
monoenergetic neutrons are used, which correspond exactly
to large resonances in the nitrogen and oxygen
interaction cross sections (interaction probabilities),
the signal to noise ratio of the system is favorable,
35   leading to high sensitivity and specificity for
quantitatively detecting the elements of interest.
Furthermore, at there low fast-neutron energies, neutron

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activation and the subsequent conversion to radioactive
elements does not occur with the neutron used in this
invention. These and other advantages of the invention
will be readily apparent from the drawings, discussion
5 and description which follow.

    The contents of any references cited in the
specification are hereby incorporated by reference.

SUMMARY OF THE INVENTION

    It is thus an object of the invention to
10 provide a novel method for detecting the presence of
certain elements in a container or other object. More
specifically, it is an object of this invention to
provide a novel nuclear detection method and apparatus
for detecting the presence of characteristically high
15 levels of oxygen and nitrogen in a region within a
container, as a screening technique for determining the
presence of an explosive, in parcels and baggage that are
transported by passenger aircraft.

    The present invention relates to a neutron
20 resonance detector system that uses neutron out-
scattering to identify the existence of certain elements
that are present in the object being examined. The
device includes an accelerator which produces
monoenergetic low energy fast neutrons at several
25 specific energies, and detectors which measure
monoenergetic neutrons which have passed unscattered
through the object of interest. The object to be scanned
is positioned between the accelerator and the detecting
device. Neutrons that pass through the object
30 unscattered are detected by the device.

    In carrying out this invention, monoenergetic
neutron beams at several specific energies are directed
onto the object to be examined. At these low energies
and with appropriately chosen neutron production targets,
35 each angle of the neutron beam produced at the target
corresponds to a particular neutron energy. The
detectors, present at specific angles corresponding to

the neutron energies of large resonances (peaks) in the
total neutron cross sections of the elements being
detected, measure the number of neutrons that pass
through the object unscattered. If large amounts of an
5 element are present in some part of the object, the
nuclei of that element will scatter neutrons traveling at
the specified energy and thus fewer neutrons will pass
unscattered through that part of the object being
examined. The device compares the number of neutrons
10 which enter the object versus the number of the neutrons
that exit the remote side and are detected by the device.
What is being measured is thus the inclusive removal of
neutrons of specified energies from their initial energy
and direction by all nuclear processes by the material
15 (elements) inside the object. Based on this information,
a computer connected to the detectors can first calculate
the density of the elements being detected along the path
of the unscattered neutrons, and then, based on this
information for all the measurements taken along
20 different paths though the object of interest, a computer
connected to the detectors can then perform the
calculations for tomographic unfolding. This provides a
"picture" of the densities of specified elements in the
object of interest. Furthermore, the computer can
25 provide an integrated measure of nitrogen and oxygen
densities across different planes in the bag, as well as
the entire bag, in order to detect substances in thin
sheet form.

BRIEF DESCRIPTION OF THE DRAWINGS

30   The invention will be described in greater
detail with the aid of the following figures.

        Fig. 1 is a scatter-plot of densities of oxygen
and nitrogen in various materials, including explosives.

35   Fig. 2 is total neutron cross sections for
different elements in the energy range from 0.3 to 0.5
MeV. The full curve is nitrogen, showing a narrow